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Space-Science Activities in the United States Space Programme (1)

by

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Hugh L. Dryden (2) and Homer E. Newell (3) N63 85038

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(2) Deputy Administrator, National Aeronautics and Space Administration

(3) Deputy Director, Office of Space Flight Programs, National Aeronautics and Space Administration

INTRODUCTION

The National Aeronautics and Space Act of 1958 established a new civilian agency, the National Aeronautics and Space Administration, to lead a vigorous national effort in the advancement of space science and technology and their application to peaceful purposes for the benefit of all mankind. The responsibilities of the former National Advisory Committee for Aeronautics for aeronautical research were transferred to the new agency. The general objectives of aeronautical and space activities listed in the Act may be summarized as follows:

1. Expansion of knowledge of phenomena in the atmosphere and space.
2. Improvement of aeronautical and space vehicles.
3. Development and operation of space vehicles.

4. Study of the potential benefits to be gained for mankind through space activities.
5. Preservation of U. S. leadership in aeronautical and space science and technology, and in the application thereof to peaceful activities.
6. Interchange of information between the civilian agency and agencies directly concerned with national defense.
7. Cooperation with other nations in aeronautical and space activities and in peaceful application of the results.
8. Effective utilization of the scientific and engineering resources of the United States in achieving these goals.

The total NASA program is made up of a number of elements designed to constitute a balanced program in which the United States can move ahead vigorously in all important areas of aeronautics and space activities. It would be unrealistic to deny that the space activities of the Soviet Union are a very real factor in spurring the U. S. space activities. At the same time, it is believed that the NASA program meets very real short- and long-term needs of the United States and other free nations of the world.

This total program requires and obtains contributions from nearly every field of science and engineering. Physicists play a very important role not only in advancing space science but also in the basic research which makes possible expansion of the frontiers of technology required for the development and exploitation of space vehicles. Moreover, physicists constitute a very influential body of citizens, and hence need to understand the total program and interpret it to their fellow citizens. Therefore the first part of this paper reviews the structure of the total program.

The second part of the paper considers in more detail that part of the program concerned with the first general objective stated in the Space Act, i.e., atmospheric and space science. After discussion of the specific objectives and general philosophy of the NASA space science program, some of the results obtained to date will be reviewed and plans for the future will be presented in broad outline.

THE NASA PROGRAM

The overall program includes research in aeronautics, and research and development in space science and technology, including atmospheric and space science, supporting research and technology, the development of space vehicles, the application of space techniques and knowledge to practical uses, and the manned exploration of space.

In aeronautics, the present emphasis reflects the more urgent current needs and demands of commercial and military aviation. The program includes research on problems of supersonic aircraft, particularly those of the prospective civil supersonic transport aircraft; research on vertical takeoff and landing and steep takeoff and landing aircraft; research on certain operational problems; high-speed high-altitude flight research with the X-15 research airplane to advance the frontiers of speed and altitude; cooperation with the Air Force and industry in the succeeding Dyna-Soar Project; and research on problems of re-entry into the earth's atmosphere at orbital and escape speeds.

The most visible features of the space program are the launchings of space vehicles from the Atlantic and Pacific Missile Ranges and from the NASA Wallops Station. These space flight missions fall into three categories. The first includes those missions directly concerned with the manned exploration of space, extending in the foreseeable future to the moon and planets. The Mercury program is a first-step toward this long-range objective. From the establishment of NASA much of our advanced research and technology has been planned to attack the problems to be encountered in the travel of man to the moon and his safe return to earth. As we advance toward this goal, we must reach such intermediate goals as a manned space station in orbit about the earth and the flight of man to orbit the moon and return. The Apollo program, to follow the Mercury project, is aimed at the development of a spacecraft for a crew of three capable of re-entering the earth's atmosphere on return from the distance of the moon without excessive heating or deceleration. Circumlunar flight was one of the stated goals in NASA's first Ten-Year Plan developed in early 1959. On May 25th President Kennedy stated in a message to the Congress: "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to earth." Proposals for funds to implement this program are now before the Congress. The setting of such a goal would integrate and motivate the rapid advancement of the frontiers of science and technology in many fields as needed for such a difficult goal. These developments would enable rapid exploitation of applications as the need appears, not only in the space field but in other industrial areas where new materials, new electronic components, new computer techniques and other advanced technology accelerates progress. In this manner we may insure ourselves against technological or military surprise from others who exploit the frontiers of knowledge more rapidly. The many activities which the goal of manned lunar landing and return would generate include greatly increased support to basic and applied research in many areas of the physical and life sciences.

The second category of space flight missions includes those leading to the applications of earth satellites to such areas as meteorology and communications. The meteorological satellites, TIROS and NIMBUS are still in the earliest research and development stage as regards the instrumentation, yet the results from TIROS have already opened new vistas to the forecaster and research scientist alike. In the communications area, the ECHO satellite program has laid the initial groundwork for the use of reflector satellites in passive radio communications links. Research on passive communications satellites will be continued. In addition, NASA will conduct research on active communication satellites in low-altitude orbits.

The third category of space flight missions is that devoted to space science which will be discussed more fully in a later section of this paper.

The missions represent the current activities in space in the public view, but these are dependent on the availability of a suitable launch vehicle, of a spacecraft provided with the required instruments and equipment, of a launch site, and of a world-wide net of ground facilities to receive and record data by telemetry, to track the spacecraft for determining its position continuously, to photograph its track, send command signals, or do whatever else may be required by the mission. These components and facilities must be carried out in proper time phase to be completed at the mission date.

We will discuss here only the launch vehicles. There is a rather long list of sounding rockets available for atmospheric and exploratory space research. The space vehicles now in use or under development in the NASA program are: Scout, Delta, Thor-Agena B, Redstone, Atlas, Atlas-Agena B, Centaur, and Saturn. As the development work proceeds, the vehicles will provide a steadily increasing payload and mission capability. The first version of the Saturn, called Saturn C-1, will permit launchings of 19,000-pound payloads into near earth orbits, or several tons to escape from the earth. Something beyond the Saturn class of vehicles will be required to accomplish manned landings on the moon and return to earth. The recommendations before the Congress contemplate the initiation of development of both a solid-propellant and liquid-propellant version of a suitable vehicle, presently called NOVA. The liquid-propellant version would be based on the use of clusters of several F-1 engines, each of 1,500,000-pound thrust. This engine has been under development for several years.

Continuing the description of the structure of the program to activities applicable to missions still farther in the future, we find that the launch vehicle, spacecraft, and tracking and data network activities must be supported and preceded by an ever-growing stockpile of new developments in technology in such fields as electrical propulsion, power supplies, bearings for use in space and instrumentation and new scientific knowledge from basic and applied research in almost every branch of science and technology from magneto gas dynamics to cosmology and from materials to biology.

THE NASA SPACE SCIENCE PROGRAM

Returning now to the space science program, the more specific objectives of the space science activity are:

1. To investigate the earth and its atmosphere, and the influence of the sun upon the earth.
2. To study and understand the nature and history of the earth, the solar system, and the universe.
3. To search for the presence of life outside the earth.

4. To secure the scientific information with respect to the space environment needed in the design of spacecraft adequate to explore the solar system both by instruments and by man himself.

NASA began its space science program by building upon the rocket sounding research that started immediately after the close of World War II, and upon the rocket and satellite research of the International Geophysical Year. Nearly all of the scientists who conducted rocket or satellite experiments during the IGY, and many others, are participating in the NASA program. NASA relies heavily on the national scientific community for the strength and vigor of its space science program.

NASA regards the opportunities to perform experiments in satellites and space probes as a national trust, which must be made available to those scientists in the national community who are best able to make effective use of those opportunities. To expand upon and develop these opportunities, NASA is continuing to develop payloads and spacecraft to carry experimental equipment to make the measurements and the observations required to carry out the exploration of space. Among the specialized spacecraft in use or under development are the previously mentioned TIROS and NIMBUS satellites for meteorological and related investigations, the Orbiting Geophysical Observatory for exploring the earth's atmosphere and the space environment of the earth out to more than 100,000 km, the Orbiting Solar Observatory for solar physics and related studies, and the Orbiting Astronomical Observatory for precision type astronomical observations. To press the exploration of the moon and planets, there are the lunar spacecraft, Ranger, Surveyor, and Prospector, and the planetary spacecraft, Mariner and Voyager. These have been described in detail in a number of articles and presentations (1, 2).

NASA would be pleased to hear from any interested scientists their suggestions or proposals for experiments to take advantage of the opportunities provided by these spacecraft.

NASA policy with regard to the publication of space science data collected in its programs conforms with scientific practice. Experimenters are expected to publish their data in analyzed form and their interpretation in the open literature. At the same time, NASA maintains its own publication of results from NASA-sponsored projects. On occasion, these publications may be simply reprints of articles in the open literature. However, the NASA publication affords the opportunity for a more extensive and more detailed account of the project. Moreover, the NASA publication can undertake to publish tables of reduced data that would not be accepted by and could not be handled by the professional journals.

It is NASA policy that the experimenter shall have sole use of the data obtained from his experiment for a period of time sufficiently long to accord to the experimenter his rights as the conceiver of the experiment. On the other hand, because a tremendous amount of money and the supporting work of a very large team of people go into carrying out the experiment, and because the data may be of widespread interest to the scientific community, NASA will make an arrangement, satisfactory to the experimenter, for general release of the data after an agreed-on interval. For example, it might be agreed that after a year from performance of a satellite experiment, the appropriately reduced and calibrated data might be offered to the general scientific community for their use. In some cases, the agreed-on period of time might be shorter, in others, longer than one year. Or, as has been done in the past it might be agreed with the experimenter that the scientific community be invited to record the signals from a given satellite, and that the telemetering code and calibrations be made available to interested scientists so that they can collect, reduce, and analyze the data as though they were themselves performing the experiment. In any event, the disposition of the experimental data will be worked out in prior arrangements with the experimenting scientists.

RESULTS OBTAINED IN THE NASA SPACE SCIENCE PROGRAM

Somewhat less than a year ago, Bruno Rossi (3, 4) reviewed the scientific results of experiments in space completed prior to the summer of 1960. It seems reasonable in the present paper to pick up where Rossi left off, rather than to go back once more to the very beginning of the space science program. Moreover, in reviewing the program results, we shall not attempt to go into detail on every subject, but rather shall confine ourselves to the highlights of the program.

Moon and Planets

In the scientific exploration of the moon and planets, the past year has been one largely of preparation. There was, however, one result of especial interest. Almost daily from March 10 to May 10, 1961, W. K. Victor, R. Stevens, and co-workers of the Jet Propulsion Laboratory established radar contact with the planet Venus (5). Using facilities of the NASA deep space tracking station at Goldstone, California, the JPL workers set up a Venus radar system with the parameters given in Table 1. Using different receiver configurations, four different types of data were gathered: (1) received signal level, (2) power spectrum of the Venus reflected signal, (3) velocity of Venus relative to the Earth, and (4) distance between the Earth and Venus.

From the signal level, information was obtained about the radio reflectivity of Venus, which turns out to be a much better radio reflector than the moon. At the frequency used, 2388 mcs. per second, the planet appears to have a reflectivity of 10 to 15% of that possessed by a polished conducting sphere of equal size. In contrast the value for the moon is on the order of 2%.

From the power spectrum, it was possible to make some deductions about the rotation rate of Venus. Spectral analyses of the signal indicated that Venus rotates at an extremely slow rate, perhaps only once per revolution about the sun. This remains, however, a question for continued investigation.

The principal result of the experiment was the determination of a new value for the astronomical unit. This was obtained using both the velocity and distance data. The preliminary value is 149,599,000 ± 1500 kms. It is expected that further data reduction and analysis will reduce the uncertainty by another order of magnitude.

Astronomy

In the field of astronomy, rockets and satellites have opened up an entirely new range of observations, namely, those in the wavelengths that cannot penetrate the earth's atmosphere to reach observatories on the ground. Here again, the past year has been very much one of preparation, as work went forward on an Orbiting Solar Observatory and an Orbiting Astronomical Observatory. In addition, there were some successful rocket and satellite experiments.

The Goddard Space Flight Center used sounding rockets fired from Wallops Island, Virginia, for astronomical studies. These rockets were instrumented to afford broad band stellar photometry and low dispersion stellar spectroscopy. The results from one such rocket fired to approximately 180 km from Wallops Island on 22 November 1960, at 0342 are particularly interesting, and will be reviewed here. The experimenters, J. E. Milligan, and T. P. Stecher, of the Goddard Space Flight Center, give these results in detail in papers to be presented at the Nantucket meeting of the American Astronomical Society this month (6).

Low dispersion spectra down to about 1600 A were obtained for ten stars. The resolution achieved was about 50 A. Only very bright stars were recorded, varying in temperature from slightly hotter than the sun, up to the hottest stars observable in the sky. The ultraviolet spectrum of only one of the stars agrees well with the prediction of existing theory. In this case, the star was among the cooler ones, about 7000° K, and the spectrum followed closely what one might expect from a knowledge of the sun. However, the hotter the star, the greater the disagreement with current theory. Since all the stars observed are relatively close to the earth, the observed effect does not appear to be due to interstellar absorption, but rather to involve the stellar atmosphere itself. To explain the observations, apparently a new source of opacity in the hot stars is required.

On the same flight, the rocket instrumentation observed a strong ultraviolet aurora in the range from roughly 1500 A to 2200 A. The aurora was observed at a 45° elevation angle to the north of the rocket, and was observed all the way up to the peak of the rocket flight, indicating that the source of the auroral radiation was at a considerable height. There was no visible counterpart of this ultraviolet aurora, although a very faint visible aurora had been seen at Yerkes up to shortly before the time when the rocket was fired. A very weak magnetic bay was observed at the time of the rocket firing. Milligan and Stecher suggest that the ultraviolet aurora may be caused by particle excitation of N_2, or 0_2, or both.

It appears that the particles may have been dumped from the inner Van Allen Belt or the slot between the inner and outer belts, or from both; it seems highly unlikely that the particles could have come from the outer belt.

In another series of rocket experiments, A. Boggess made a number of broad band photometry measurements (7, 8). The photometry equipment was capable of observing hot stars down to magnitude 4.5 or 5, and yielded data on about 100 stars, enough to make a statistical study possible. The observations were made at 2600 A and 2200 A with 200 A band pass filters. The instrumentation was strongly selective, and recorded only stars at the very hot end of the Hertsprung-Russell diagram. From the measurements energy fluxes could be obtained, and by a comparison of the fluxes in the different wavelengths, it was possible to specify colors for the stars. The colors obtained agreed with those given by the stellar spectra discussed above. Flux remained constant or actually decreased as the wavelength decreased, again indicating that current theory does not give the correct answer.

Boggess has attempted measurements in the 1300 A region. These have yielded a measurement on one star with a large probable error, and permitted setting an upper limit for one other star. Both observations, however, are consistent in showing that the ultraviolet flux is about one order of magnitude less than current stellar models would predict. It should be noted that these results are in contrast with recent Naval Research Laboratory measurements, which indicate at most a slight difference from current theory.

The first major step into the field of gamma ray astronomy was taken with the launching of the satellite Explorer XI (1961 Nu 1) on 27 April 1961. This satellite, which is still in orbit and transmitting, contains an experiment designed and prepared by Kraushaar and colleagues of the Massachusetts Institute of Technology to detect extraterrestrial high energy gamma rays in the 100 mev region resulting from neutral π meson decay. The intent is to map the spatial distribution of the decay gamma rays with particular emphasis on the plane of the galaxy, the galactic circle, the sun, and the Magellanic Clouds. The gamma ray count rate is extremely low, as expected, and it is estimated that about six months of observing will be required to obtain the necessary amount of data to make a successful experiment. In addition, because the apogee of the satellite's orbit is higher than had been intended, the satellite spends about 60% of its time in the Van Allen belts, during which period, although good data on the belts are being recorded, no useful gamma ray data are obtainable. The MIT group reports, however, that gamma ray counts from space are being recorded when the satellite is outside the Van Allen belts. Also, when the telescope is pointed toward the earth an appreciable gamma ray albedo count is observed.

Geophysics

Ever since rocket sounding of the upper atmosphere began, and especially during the International Geophysical Year, rockets have spearheaded a vigorous attack on problems of the upper atmosphere, obtaining results that could not be obtained from observations at or near the surface of the earth. With the launching of the first satellites during the International Geophysical Year, the investigation of the earth's atmosphere was extended even further, reaching out to the earth's environs in space. In addition, satellites, like the tiny Vanguard I, have proved to be an effective tool in determining the size and shape of the earth, and the distribution of matter within it.

Geodesy

Observations of gravitational perturbations on satellite orbits first gave an improved measurement of the earth's oblateness, yielding a value $(1/(298.2 \pm 0.2))$ that indicated that the earth's mantle is not perfectly plastic (9, 10). Continued study of satellite orbits showed that the earth's figure has a slight pear-shaped component, amounting to a 15 meter peak at the north pole and an equal flattening at the south pole (9, 10). According to O'Keefe, these results indicate a mechanical strength at the base of the mantle of 2×10^7 dynes per cm, or about the strength of ordinary brick. These results are well known by now.

During the past year, Izsak of the Smithsonian Astrophysical Observatory reported still further results on the earth's figure (11). Analysis of photographic observations on the satellites 1959 Alpha 1 and 1959 Eta enabled Izsak to evaluate the dominant longitude-dependent term of the geopotential. The results indicated a decided eccentricity in the earth's equator, corresponding to an ellipticity of $(3.21 \pm 29) \times 10^{-5}$. If this is truly a geometric eccentricity, it amounts to about 400 meters difference in length between the longest equatorial diameter and the shortest, with the maximum diameter corresponding to longitude -33.°15 ± .°35.

Meteorology

The first TIROS satellite launched a new powerful attack on the study of the earth's atmosphere. Pictures from TIROS I indicated that individual storm types have distinct cloud vortex characteristics. They showed striking patterns of large spiral cloud formations, some 2500 km in diameter. In some of the photographs, jet streams, thunderstorms, fronts, and regions of moist and dry air were discernible. Where there were no obscuring clouds, large ice packs could sometimes be seen.

During the past year, TIROS II was launched on November 23, 1960. Like TIROS I, this satellite carried both wide angle and narrow angle cameras. Unfortunately, the pictures obtained with the wide angle camera were of poorer quality than those from TIROS I. Nevertheless, they do disclose large cloud masses and clear areas, and have proved useful in day-to-day weather analyses and forecasting. The narrow angle camera pictures are of excellent quality.

Before the launching of TIROS II, 21 countries were offered the necessary orbital data if they desired to conduct special meteorological observations that could then be correlated with the satellite observations. Ten of the seventeen countries that had indicated a desire to participate chose to proceed with their planned programs even though the wide-angle picture quality was poorer than intended.

In addition to the equipment for obtaining cloud pictures, TIROS II carried infrared sensors to observe the radiation from the earth and its atmosphere. The measurements made by these infrared detectors are as follows: temperature of the top of the water vapor layer (6.3 microns); surface temperatures or cloud top temperatures (8 to 12 microns), which helped to distinguish cloudy areas at night; the amount of reflected radiation (0.225 microns); the amount of emitted radiation (7 to 30 microns); and low resolution cloud pictures (0.5 to 0.7 microns). These data are under analysis by the NASA Goddard Space Flight Center and the U. S. Weather Bureau.

A paper has already been prepared on the TIROS II radiation measurements, and will be published (12). The data were reduced by hand, a slow and laborious process. Since then automatic data reduction has been in use. The results will be published as rapidly as they become available.

During the past year Suomi has obtained preliminary results from the earth's heat balance experiment carried aboard Explorer VII (13). The results showed that the earth's heat balance depends almost entirely on the distribution of clouds. More infrared radiation leaves the earth from clear areas than from cloudy ones, regardless of the temperature of the air masses. It is, therefore, possible to obtain crude maps of weather systems with the very simple temperature measuring devices used by Suomi in the Explorer VII experiment.

Not as sweeping as the TIROS program in scope, yet important to meteorology, was the program of meteorological rocket soundings carried out by a number of agencies in the United States during the past year. These firings were conducted at regular intervals throughout the past year from launching sites at Cape Canaveral, Florida; Eglin Field, Florida; Fort Churchill, Canada; Fort Greeley, Alaska; Pacific Missile Range, California; Tonopah, Nevada; Wallops Island, Virginia; White Sands, New Mexico; and Kauai, Hawaii. In 1960, 304 small sounding rockets were launched, and the activity is continuing in 1961.

The rocket network has yielded a tremendous amount of data on winds and temperatures in the upper atmosphere between 15 and 60 kms altitude (14). The wind data over the American continent appear to be very good. They show essentially the same picture as that revealed by the grenade experiments conducted during the International Geophysical Year. Winds are generally from the east in summer and from the west in winter over the northern hemisphere, and increase in magnitude as one approaches the pole. The network data also show breakdowns in the normal circulation during the period January through

April similar to those that had been observed previously in January 1958 at Fort Churchill, Canada. Circulation reversals over Wallops Island, observed during January and February 1961 are of especial interest because of the change of snow storm patterns in this area which occurred during the same time period.

Whereas the wind data obtained from the rocket network has been very good, the temperature data are poor. Apparently, the thermistors used for the temperature sensors do not give useful measurements above 40 km.

During the past year, NASA conducted a number of rocket firings at Fort Churchill in Canada and at Wallops Island in Virginia to obtain upper air winds and temperatures by means of the grenade technique. In this experiment, grenades are ejected from the flying rocket and exploded, and the transit times of the sound rays from the explosions to listening stations on the ground are recorded. These transit times are then used to determine the upper winds and temperatures. Good measurements can be made over the altitude range from 30 to 80 kilometers. Since the technique has been described in detail in the open literature, (15, 16) we will not dwell upon a description of it. The firings of the last year showed that the upper atmosphere over Wallops Island, Virginia, resembles very much that observed over Guam and White Sands. The data are still being analyzed by members of the Goddard Space Flight Center, and will be published as soon as the analysis is completed.

High Altitude Winds and Turbulence (17, 22)

The past year saw the continued development and application of the sodium vapor technique to a study of winds in the ionospheric regions from 80 km to over 400 km. In these firings, sodium vapor is ejected from the flying rocket either in bursts or as a continuous trail as the rocket ascends. The firings are always conducted at twilight, either in the morning or in the evening, so that the sodium vapor is illuminated from the side by the sun. Under irradiation by the sunlight the cloud glows in the familiar sodium D lines. The drifting and twisting of the vapor trail gives information on the turbulence, wind shears, and winds in the upper atmosphere. The expansion of the cloud gives information about diffusion rates and densities in the high atmosphere. Blamont has developed the use of interferometric and absorption techniques to measure upper air temperatures from observations of alkali metal vapor clouds (21).

Using equipment developed and prepared by the Geophysics Corporation of America, sodium vapor trails were released above Wallops Island, Virginia, at altitudes from about 75 km to 200 km at 1948 EST on 24 May 1961, and from 75 km to 145 km at 0630 EST on 9 December 1961. High speed winds and considerable turbulence were observed up to altitudes of about 110 km. In the regions of turbulence, vertical motions were measured having speeds between three and seven meters per second (20).

On 10 December at 1730 EST, sodium vapor was ejected as clouds at altitudes of about 370 kms, and about 710 kms. Actually the ejection took place at somewhat lower altitudes, but the velocities imparted to the clouds by the motion of the rocket carried them to the stated altitudes where they were observed. Lithium vapor was ejected on this same flight at an altitude of 680 kms. Photographs of the clouds were obtained by five ground stations at different, widely separated locations. From observations on the 370 km burst, Blamont estimated the atmospheric temperature to be 1450 $\pm$ 75° K (22). From the same cloud, Manring deduced a wind of about 80 meters per second at 370 kms; a diffusion coefficient of 2.7×10^{10} cm^2/sec, good to $\pm$ 30%; and an atmospheric density of 6×10^8 molecules and atoms per cubic centimeter, correct to within $\pm$ 40%. For the density determination the atomic weight was assumed to be 16, corresponding to atomic oxygen as the principal atmospheric constituent.

Atmospheric Structure

Satellites have continued to yield information on the structure of the earth's outer atmosphere. In a recent report to the Committee on Space Research at its meeting in Florence, Italy, during April of 1961, L. Jacchia presented the results of an analysis of the orbits of seven satellites with perigee heights lying between 205 and 1121 km (23). The analyses showed very clearly that during the November 1960 events, the atmospheric drag on all of the satellites was perturbed. The perturbations closely paralleled the geomagnetic index curves. The amplitudes of the perturbations varied from a factor of two to a factor of eight, and showed a tendency to increase with height. However, there was little correlation with latitude or with position relative to the sun. The evidence is clear that emanations from the sun during these periods of activity have an effect upon the atmosphere, and the most immediate explanation appears to be that the atmospheric density is increased. Since the effect follows the geomagnetic index curve, it appears reasonable to suppose that the effect is in some way caused by energetic solar particles funneling energy into the earth's atmosphere through the earth's radiation belts. However, the precise mechanism for this action has yet to be determined.

A clear-cut example of the effects discussed here was provided by the ECHO satellite which was aloft during the great solar storms of November 1960. Figure 1, which is due to Bryant of the Goddard Space Flight Center, shows clearly the marked effect on the ECHO drag produced by the large solar flares of the November event (24).

An important feature of the ECHO satellite was its huge size and correspondingly small mass to area ratio. As a consequence, ECHO was well designed for obtaining air densities at the high altitudes of its orbit. From observations on the air drag effect on the ECHO satellite, a number of workers have succeeded in determining the atmospheric density at perigee altitude. Inasmuch as the solar radiation pressure on the satellite caused the perigee altitude to vary between a little more than 1500 kms to just above 900 kms, it was possible to determine air densities over an appreciable range of heights. The results obtained by Bryant are shown in Fig. 2 (24). At 1500 kms the density is on the order of 10^{-18} grams per cubic centimeter.

Solar Radiation Pressure

The huge size of the ECHO satellite also served to emphasize another effect, already mentioned, namely that of solar radiation pressure. This effect had been observed and shown to be in keeping with what would be expected theoretically in the case of Vanguard I, on which the effect is quite small, though measurable. But in the case of the ECHO satellite the solar radiation pressure causes a change in the eccentricity of the satellite's orbit, from about 0.01 at launch to a maximum of roughly 0.07 in a period of 4 1/2 months. On January 1, 1961, maximum eccentricity was obtained, and since that time the eccentricity has been decreasing.

With the changing eccentricity, the perigee altitude of ECHO has also varied as shown in Fig. 3 (24). Starting at 1521 km at launch, the perigee descended to a minimum altitude of 915 km on 1 January 1961, since when the perigee altitude has been increasing again. This effect is cyclic, and after reaching nearly 1500 km in June, 1961, the perigee will begin to descend again. Because of air resistance, the dipping of the perigee into the lower altitudes decreases the lifetime of the satellite, probably by as much as an order of magnitude.

Ionosphere

During the past year, the NASA program has included a number of firings to study the earth's ionosphere. Rockets fired at Fort Churchill in Canada and at Wallops Island in Virginia were instrumented to measure the electron density, the ionic conductivity, and electron temperature. The Explorer VIII satellite, launched from Cape Canaveral on 3 November 1960 into an orbit with a 50° inclination, carried 10 experiments, including an electron current monitor, an ion current monitor, and an electron temperature probe, for direct measurements in the earth's outer ionosphere. In a paper presented to the Committee on Space Research at its recent meeting in Florence, Italy, Robert Bourdeau of the NASA Goddard Space Flight Center reviewed results from the NASA ionospheric program obtained during the past year (25). Among the highlights were some of the results obtained from Explorer VIII.

A schematic diagram of the electron temperature probe carried in Explorer VIII is shown in Fig. 4. The probe consists of a collector located in a recess behind a grid that is mounted flush with and insulated from the satellite skin. The collector is biased positively so as to eliminate positive ion and photo emission current effects from the electron current measurements.

In alternate halves of the probe's duty cycle a variable voltage, as shown in the figure, was applied to the grid, so as to obtain a volt ampere curve for the probe. Fig. 5 shows a typical volt ampere curve obtained from the Explorer VIII data. The slope of that portion of the curve that corresponds to negative values of the grid potential yields an estimate of the electron temperature. For the curve in the figure shown, the electron temperature was estimated as 1800° ± 300° K. The intersection of the two linear parts of the volt ampere curve gives the negative of the potential of the satellite relative to the plasma. This potential was estimated to lie between zero and -0.15 volts.

The ion current monitor used on Explorer VIII is shown schematically in Fig. 6. The outermost grid was flush with and electrically connected to the satellite skin. Incoming electron current and photo-emission from the collector were eliminated by biasing the inner grid negatively. Experimental data were plotted as a function of the angle made by the normal to the collector opening with the velocity vector of the satellite (Fig. 7). From such a curve, corresponding to 1000 km altitude, on 27 November 1960 at 2257 UT, above Blossom Point, Maryland, an estimated ion concentration of 1.3×10^4 ions per cubic centimeter was obtained. The precise shape of the curve of ion current versus angle relative to the velocity vector could be explained theoretically on the basis of several assumptions, one of which postulated the presence of some positive hydrogen ions among mostly atomic oxygen ions. Thus at 1000 km perhaps the satellite was approaching the region where hydrogen becomes dominant.

By applying a saw-tooth voltage to the collector of an ion current monitor it was possible to obtain a volt ampere curve from which the mean ionic mass of the surrounding medium could be obtained. At 1000 km it was determined that the mean ionic mass was close to 16 atomic mass units, which added support to the conclusion that the satellite was at the lower edge of a region of hydrogen.

Explorer VIII also carried a total current monitor, which together with the devices described above made it possible to develop a model of the plasma sheath surrounding the satellite. It appears that there is in the wake of the satellite an electron sheath, immediately adjoining the satellite surface. Surrounding the satellite and the electron sheath to the rear is a positive ion sheath, comparable to one Debye length in thickness, which in this case was computed to be 2.5 cm. The current through the sheath surrounding the satellite consists of a positive ion current from the medium, an electron current from the medium, and a photo-emission current from the satellite. The last is effective at angles of $\pm$ 60° relative to the sun, with a maximum density value of 5×10^{-9} amp/cm^2. The presence of the earth's magnetic field has a measurable effect on the pattern of the current flow. Balancing the random electron current density against the photo-emission current, it was possible to estimate that the satellite would go significantly positive for altitudes above about 4000 km, just above the apogee altitude of Explorer VIII.

The above results from Explorer VIII come from only a portion of the total data collected. Analysis of the data is continuing and further results will be reported in the literature when available.

Solar Activity and the Interplanetary Medium

Among the most exciting areas of investigation in the NASA program has been that of fields and particles in space, the effects of solar activity on the interplanetary medium, and solar influences upon the earth's atmosphere. Interest in this area quickened with Van Allen's discovery of the Radiation Belts, and now a number of scientists are tackling a variety of problems in this area with vigor. Data obtained by Van Allen from the Explorer satellites, by Simpson, Winckler, and Sonett from Explorer VI and Pioneer V, and by Heppner and Bridge from Explorer X, provided much grist for the theorist's mill, and have led to a reasonably consistent picture of what happens between the sun and the earth following a solar flare. Because of the widespread interest in this area, it may be worthwhile to describe the picture as it appears at present.

In the period 30 March to 1 April 1960, there occurred a major solar storm including two major flares. At the time of this storm, both Pioneer V and Explorer VII were out in space. Pioneer V carried a counter-telescope, provided by Simpson of the University of Chicago, a geiger counter and ionization chamber prepared by Winckler of the University of Minnesota, and magnetometers provided by Sonett of the Space Technology Laboratories, instrumentation well designed to detect the effects and consequences of such a solar event. Explorer VII carried counters provided by Van Allen of the State University of Iowa. Pioneer V was 5,000,000 kilometers from the earth while Explorer VII was orbiting the earth at an average altitude of about 800 kilometers above the surface.

Following the first flare, Pioneer V radioed back to earth information indicating the passage of a cloud of relatively slow-moving particles enroute from the sun to the earth. Explorer VII detected the effect of the same particles on the radiation belts near the earth a short time later. The effect of the particles from this flare was also observed on the surface of the earth in the form of a magnetic storm and other disturbances. The magnetic storm began about a day after the commencement of the flare, indicating that the particle cloud traveled at a speed of about 1600 kilometers per second.

On the morning of April 1, a second major flare occurred in which a cloud of slow-moving particles was again emitted. However, this flare, unlike the previous one, also produced a burst of extremely energetic particles, which reached the earth only one hour after the commencement of the flare. Their arrival was indicated by an anomalous absorption of radio waves in the Arctic ionosphere, which was reported by Leinbach at the University of Alaska.

The passage of these fast particles across the interplanetary space was also indicated by Simpson's counters in Pioneer V. These energetic particles reached the earth by traversing the region filled with the plasma cloud and magnetic fields injected in the first flare. The circumstances of their arrival near the earth have, therefore, provided clues as to the state of the interplanetary medium at the time of the second flare, 1 3/4 days (42 hours) after the occurrence of the first large flare.

Prior to the solar storm of late March and early April, Pioneer V measurements had revealed the presence of a gigantic current ring encircling the earth at about ten earth's radii out in space.

Sonett's instruments in the Pioneer V also indicated a breakdown in the earth's magnetic field somewhere between 12 and 15 earth's radii from the earth. Throughout this region fluctuations in magnetic field were observed which may be attributable to waves created as solar particles impinge upon the earth's magnetic field. Before the occurrence of the April solar event, the Pioneer V instruments had indicated the strength of the interplanetary field to be about two gamma, and essentially normal to the plane of the ecliptic. During the solar event, Sonett's instruments observed sudden increases by a factor of 20 or so in the interplanetary magnetic field, followed by a decay back to what appeared to be the normal value of two gamma. During this period, the Pioneer V instruments also detected a Forbush decrease in cosmic ray intensity, comparable to the decrease observed on earth. It appears, therefore, that the Forbush decrease is not caused by the presence of the earth.

An unusually violent solar storm occurred on 10-12 November 1960. During this storm Explorer VII and Explorer VIII were aloft collecting data on changes in the ionosphere and upper atmosphere. In addition, a number of sounding rockets containing geiger counters and cosmic ray emulsions prepared by Davis and Fichtel of the Goddard Space Flight Center were launched into the upper atmosphere from Fort Churchill in Canada. These rockets had been shipped to Fort Churchill to await the occurrence of such a solar flare. The observations showed a large flux of solar protons associated with the November flares. The emulsions recorded tracks of heavier nucleii, the data from which are still being analyzed.

The effect of this event on the ECHO satellite has already been mentioned.

The picture that emerges from these data, and from the thinking of Gold, Dessler, Jastrow and others, appears to be the following. When a flare is situated in the right position on the sun's surface, clouds of charged particles are ejected in such a direction that they reach the earth and interact with its atmosphere. The energy carried by these particles averages less than one one-millionth of the energy in the sun's visible light, but its effects include communications blackouts and disturbances, magnetic storms, auroral displays, and violent changes in the intensity of the Van Allen radiation. Information obtained from the Explorer satellites suggests that these belts may have the function of a storage bin, in which solar flare energy is trapped for a time, before it is released to the atmosphere.

It appears that under normal conditions the interplanetary space consists of a low concentration of extremely slow moving electrons and protons, perhaps five per cubic centimeter, and a still smaller number of energetic cosmic rays, normally on the order of less than one such energetic particle per cubic meter. There is also a small interplanetary magnetic field, approximately two gamma. When a solar flare occurs, a tongue of plasma, i.e., relatively slow moving charged particles, erupts from the surface of the sun at the site of the flare, and moves out across interplanetary space at a speed of about 1600 kilometers per second. At this rate, it normally takes the plasma cloud about one day to reach the earth. The plasma cloud drags with it the lines of solar magnetic force, which are frozen into the cloud and forced to move with it by the laws of Maxwell. The lines of magnetic force have their roots on the surface of the sun in the vicinity of the flare, but as the plasma tongue moves out they are drawn out with it. As the magnetic force lines become distended in this manner they lose their strength, and by the time they reach the earth they are some 500 times weaker than they were at the surface of the sun. However, the magnetic field within the plasma tongue is still sufficiently strong to screen the earth partially from the cosmic rays which normally bombard it, thereby providing an explanation of the Forbush decrease.

The picture is as yet not complete. There are many questions yet to be answered. One of these is the question of the solar wind. If the magnetic field in interplanetary space is actually as high as two gamma at the distance of the earth, then it is hard to see how the particles of the energies usually postulated for the solar wind can traverse the interval of space between the sun and the earth. To answer this question one must make observations with plasma probes designed to observe the lower energy particles, accompanied by a suitable magnetometer to record both the quiescent fields in space and the fields accompanying the traveling particles. Such measurements were begun in the Explorer X satellite which carried a rubidium vapor magnetometer provided by Varian Associates and Heppner of the Goddard Space Flight Center, and a plasma probe designed and prepared by Bridge and co-workers of the Massachusetts Institute of Technology.

FUTURE PLANS

The NASA program will continue to press vigorously the attack upon major problems in space science. An indication of what the future program holds in store may be obtained from a look at the schedule in Table 2 which does not reflect a probable augmentation arising from the recommendations now before the Congress.

The sounding rocket program will be pushed vigorously, continuing the investigation of the earth's atmosphere and the influences of incoming radiations upon it. The observatory satellites are designed to provide for a sustained and powerful attack on geophysical, interplanetary, and astronomical problems. By providing a considerable weight capacity in the observatories, it will be possible to make large numbers of measurements and observations simultaneously, which is necessary if we are to be able to unravel the great complexities of the space phenomena under study. By standardizing the basic satellite with its tracking, telemetry, and temperature control equipment, and its power supply, it should be possible to reduce greatly the required lead-times for preparing and mounting experimental instruments in the observatory. Also by launching one such observatory per year, the opportunity is provided for introducing new equipment and experiments to follow up on discoveries made in previous observatories.

Although it is intended that the satellite observatories will bear the bulk of the burden of the geophysical and astronomical measurements, nevertheless there will always be need for special tailor-made satellites to carry out investigations that have special requirements not met by the observatories. The small satellites listed in the table are intended to cover these needs.

In keeping with President Kennedy's recent remarks the lunar program will be pressed vigorously. The flights indicated on this chart are those that were planned prior to the proposed program increase. The manned lunar program will contribute directly to the scientific investigation of the moon. In addition, the unmanned effort, shown here, will be strengthened and increased in support of the manned effort. Indeed, the entire space sciences program will benefit from the vigorous drive to achieve a landing of men on the moon and their safe return to earth.

In the planetary program, as the investigation of Venus and Mars progresses, attention will then be turned toward other planets also. Toward the end of the decade investigation of Mercury, Jupiter, and the asteroid belt will begin. The investigation of interplanetary space will eventually require the sending of probes to the vicinity of the sun, and to considerable distances out of the ecliptic plane.

The satellite and space probe flights listed in the table represent a tremendous activity. Their successful accomplishment will be a tremendous engineering achievement. Nevertheless, the flights in themselves are not the motivation behind the great effort that must go into achieving them. That motivation is to conduct science in space, to investigate and explore the solar system and in general to extend man's knowledge of the universe in which he lives. It is all important, therefore, that the experiments and observations conducted in these spacecraft be the very best possible. As stated earlier in this talk, NASA would be pleased to hear from those scientists interested in participating in the program, or who have suggestions or proposals for experiments to be done in the spacecraft.

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TABLE 1

VENUS RADAR SYSTEM PARAMETERS

TRANSMITTER FREQUENCY	2388	MCS
UNMODULATED TRANSMITTER POWER (12.6 KW)	+71	dbm
TRANSMITTER ANTENNA GAIN	53.8	db
TRANSMITTER LINE LOSS	.3	db
$\frac{\sigma}{4\pi R^2}$ AT 31 MILLION MILES	-84	db
POWER INTERCEPTED BY VENUS	+40.5	dbm
$\left(\frac{\lambda}{4\pi R}\right)^2$ AT 31 MILLION MILES	-255	db
RECEIVING ANTENNA GAIN	53.5	db
MAXIMUM RECEIVED SIGNAL LEVEL	-161	dbm
APPARENT REFLECTION AND PROPAGATION LOSS	9	db
TYPICAL RECEIVED SIGNAL LEVEL	-170	dbm
RECEIVER THRESHOLD (T = 60°K, BW = 1 CPS)	-181	dbm
TYPICAL SIGNAL-TO-NOISE RATIO	11	db

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Table 2

NASA SPACE SCIENCE PROGRAM

Schedule of Major Launchings

	1961	1962	1963 on
Sounding Rockets	85	100	100 per year
Small Satellites	8	6	Several per year
Geophysical Observatory (Eccentric Orbit)			1 per year
Geophysical Observatory (Near Earth Polar Orbit)			1 per year
Solar Observatory	1	1	1 per year
Astronomical Observatory			1 per year
Planetary & Interplanetary Probes		2	At least 1 each period to each of Venus and Mars
Lunar & Interplanetary Probes		3	Several per year
Interplanetary	3		Special missions as needed

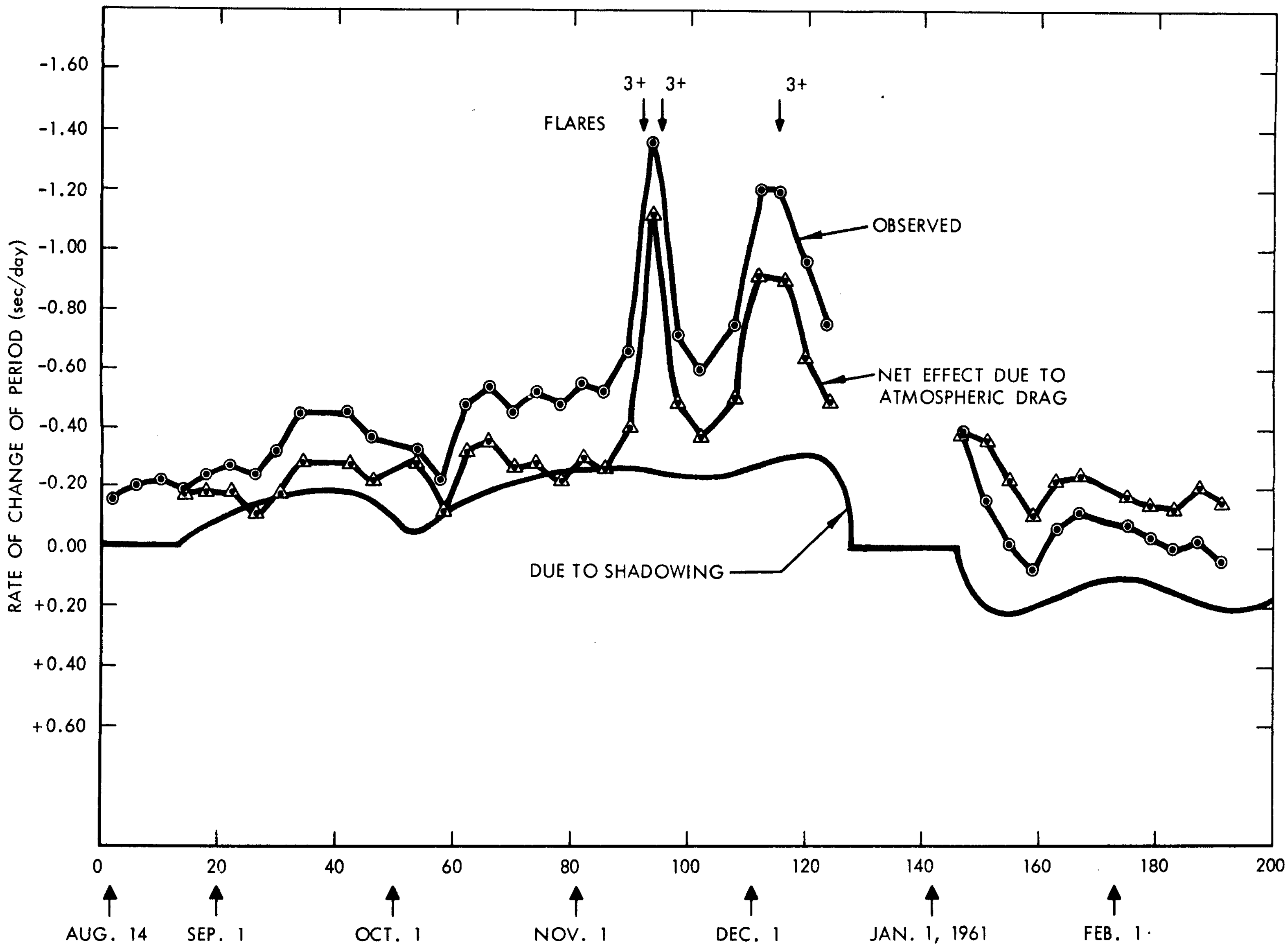


Figure 1. RATE OF CHANGE OF PERIOD OF ECHO SATELLITE

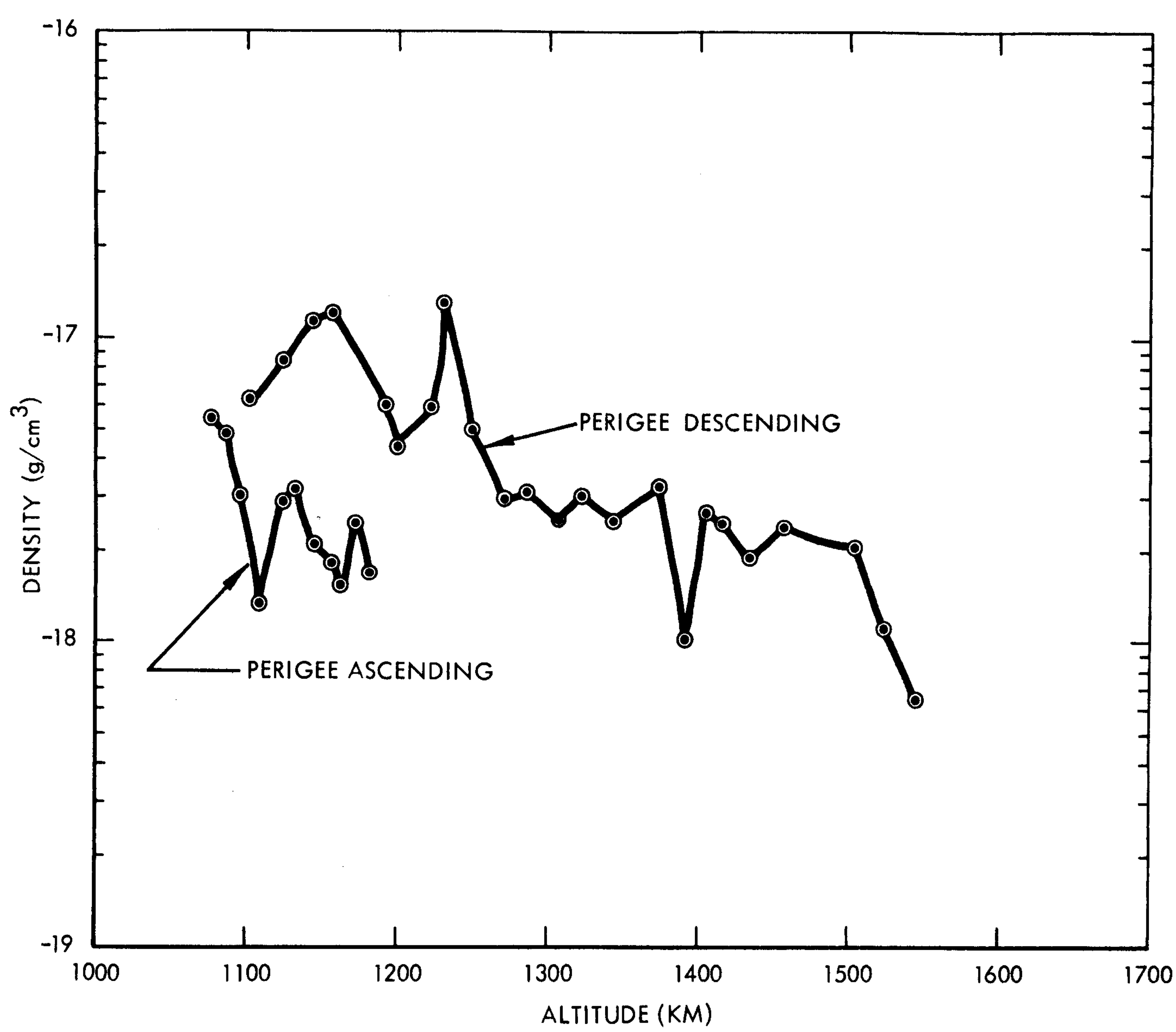


Figure 2. ATMOSPHERIC DENSITIES OBTAINED FROM ECHO I

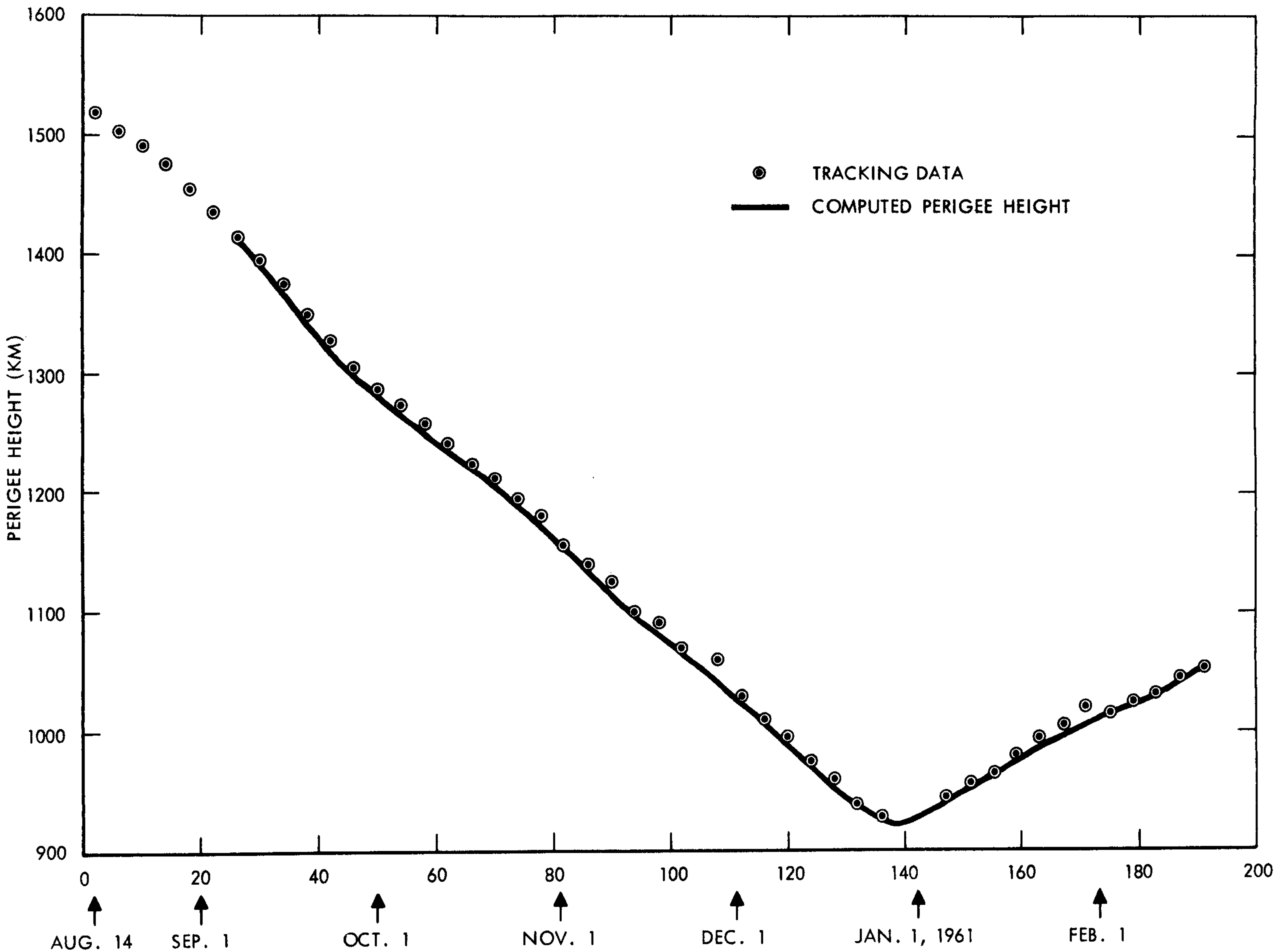


Figure 3. EFFECT OF RADIATION PRESSURE ON ECHO I

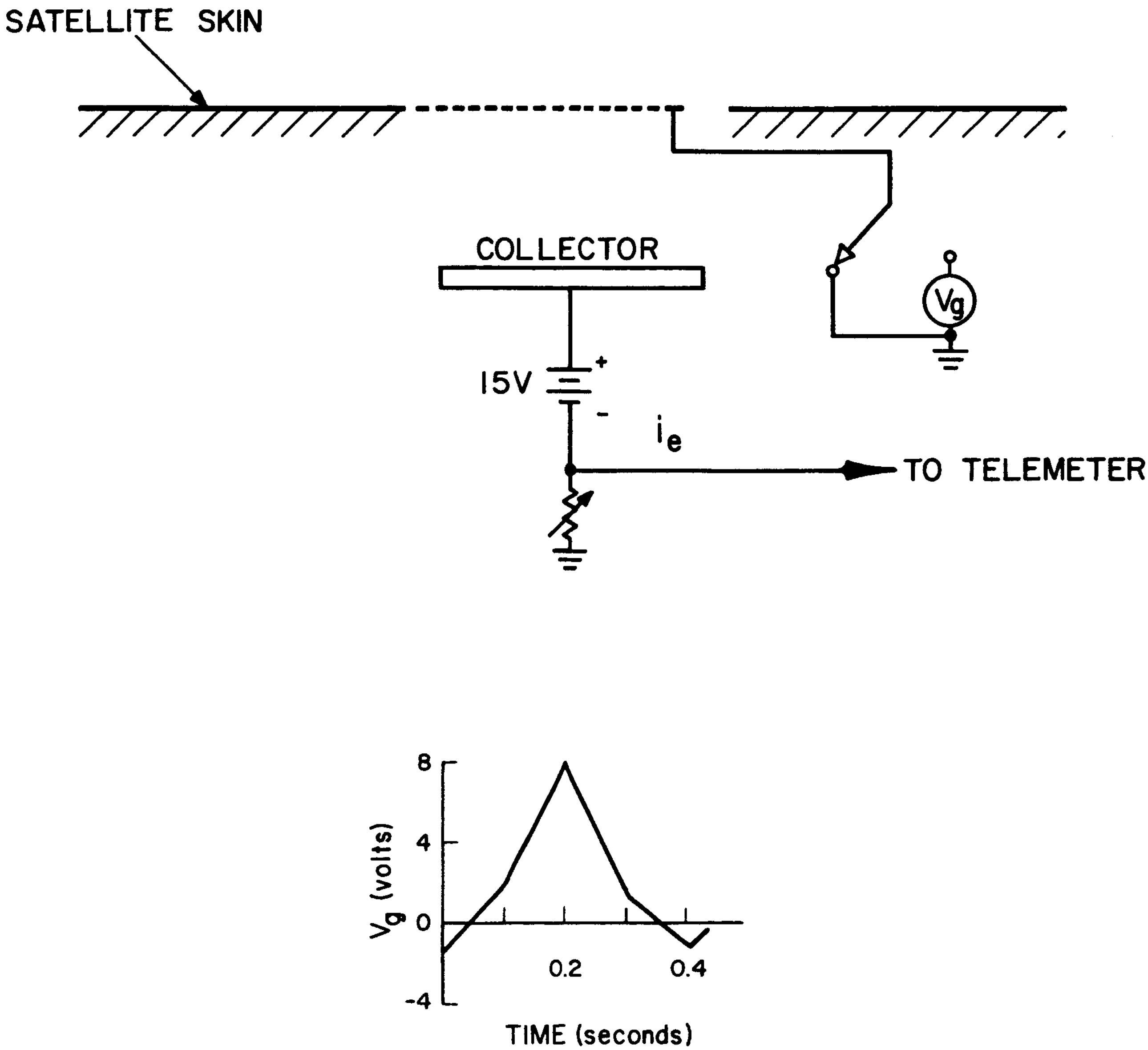


Figure 4.

ELECTRON TEMPERATURE PROBE
EXPLORER VIII SATELLITE

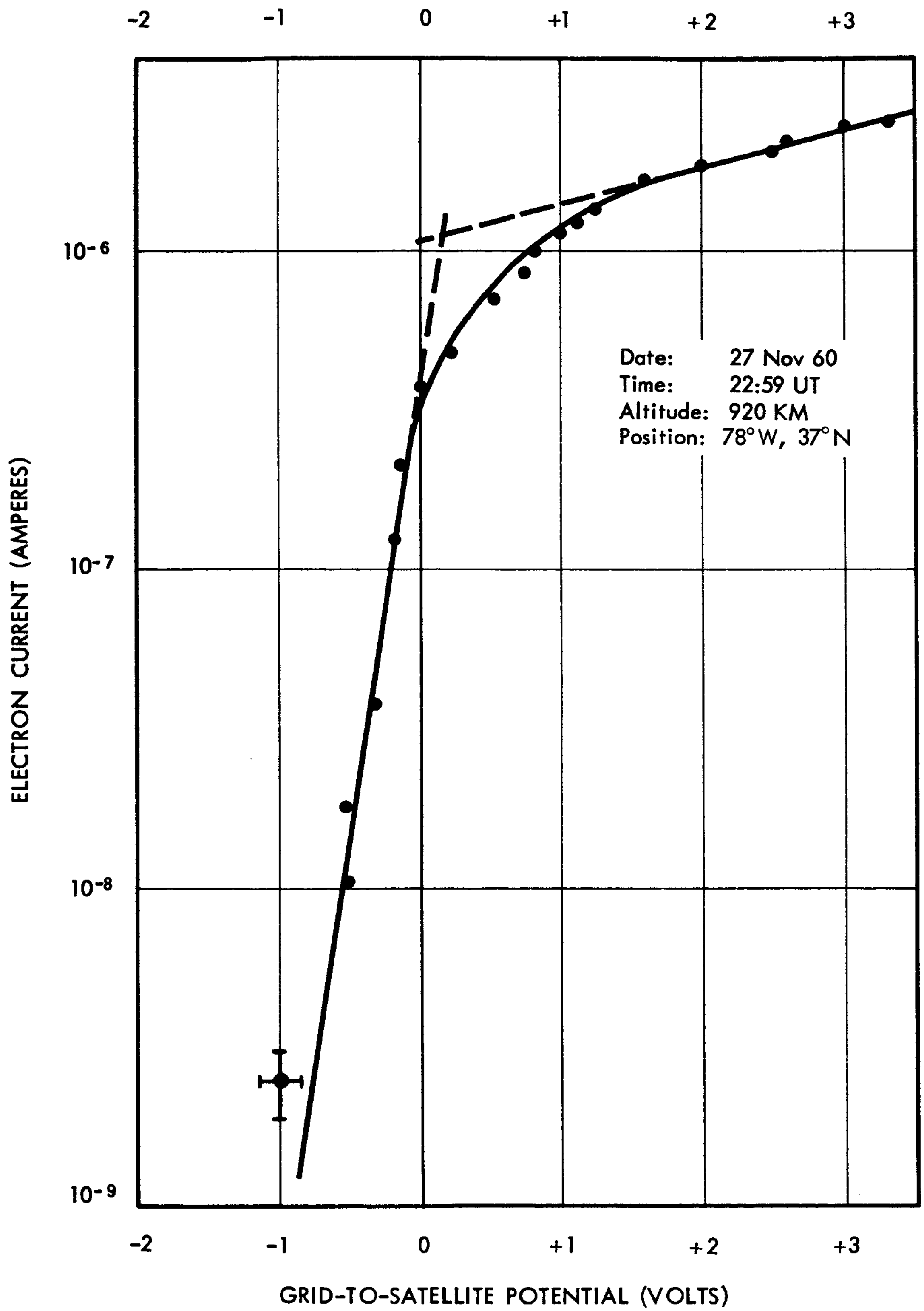


Figure 5. Typical Volt-Ampere Curve, Two-Element Electron Temperature Probe.

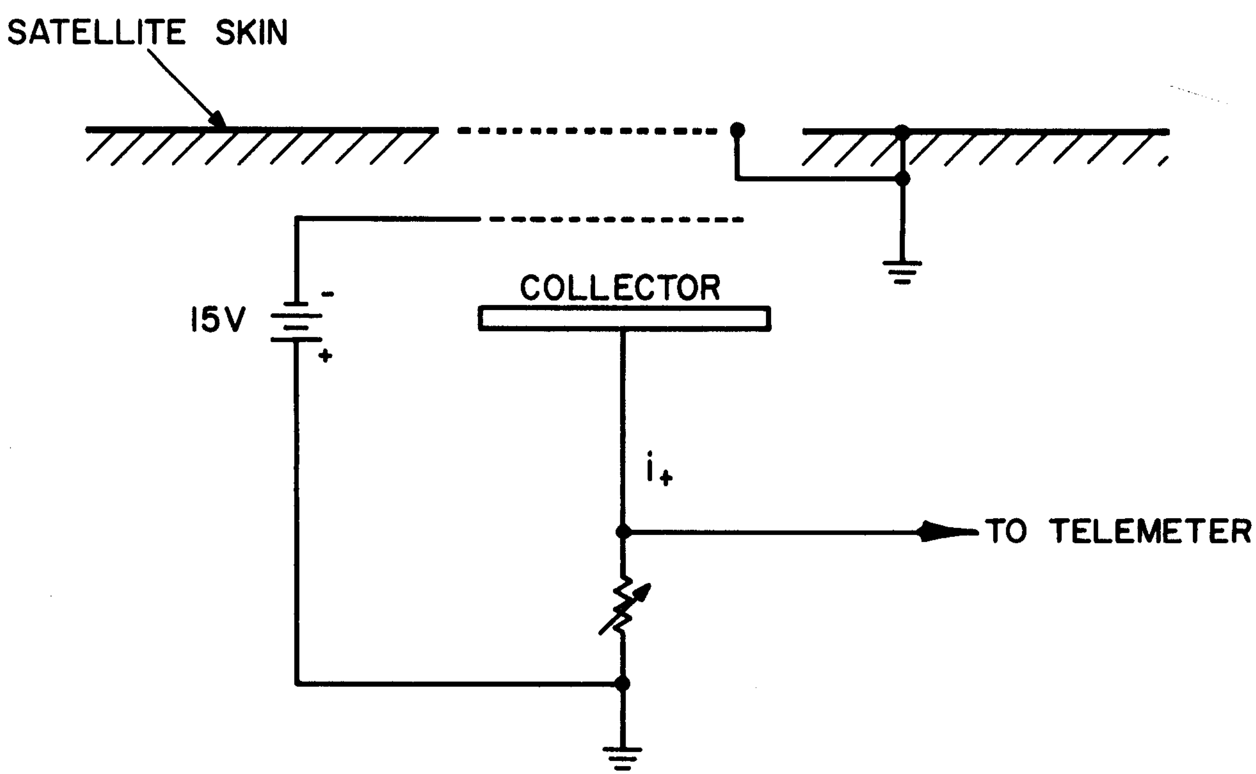
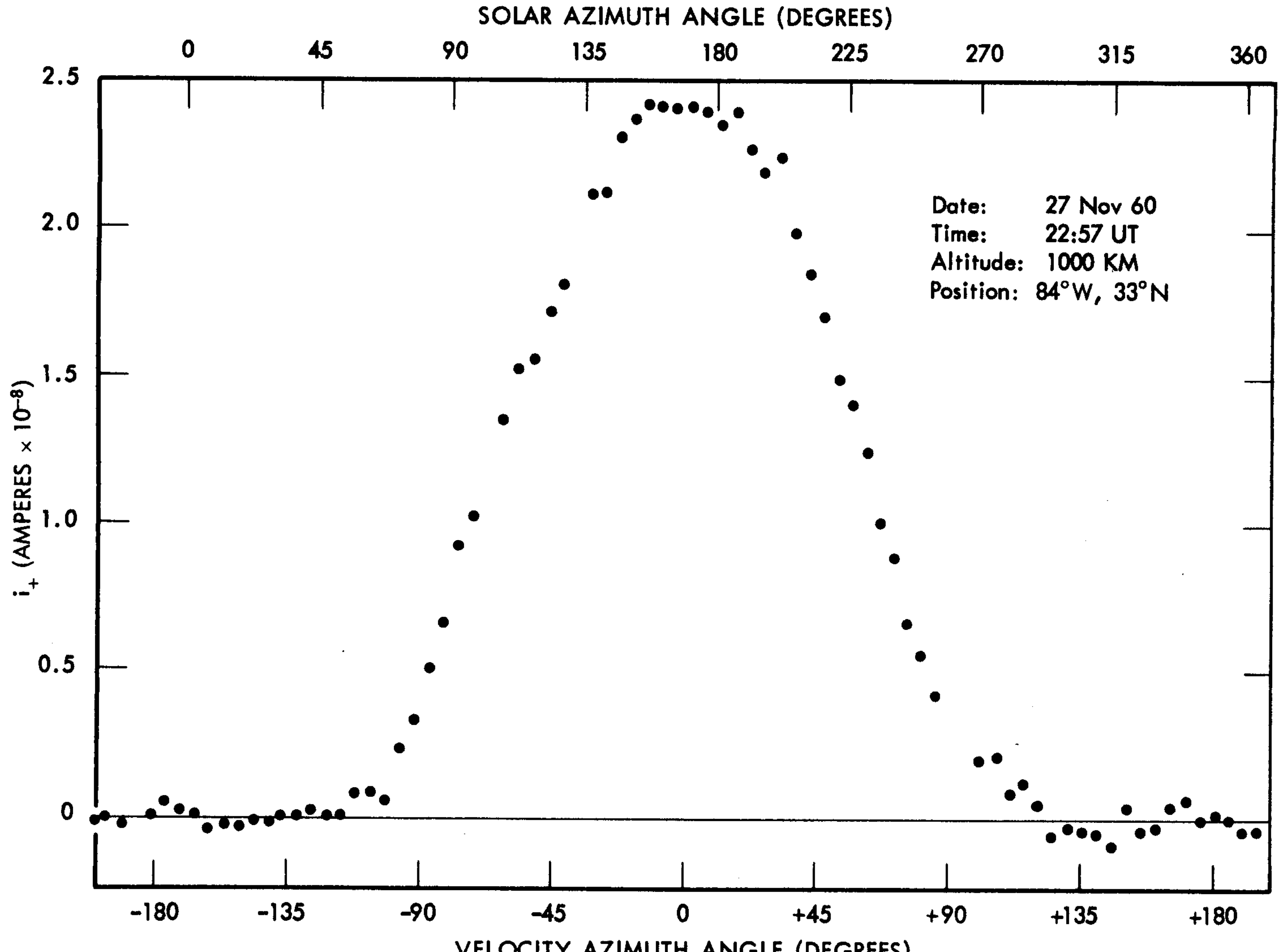


Figure 6.

ION CURRENT MONITOR
EXPLORER VIII SATELLITE



$i_+ = \alpha_+(eAN_+ \ V \ \cos\theta), \ |\theta| < 45°$

Figure 7. Ion Current as a Function of Aspect, Explorer VIII Satellite.